

Jan. 13, 1942.

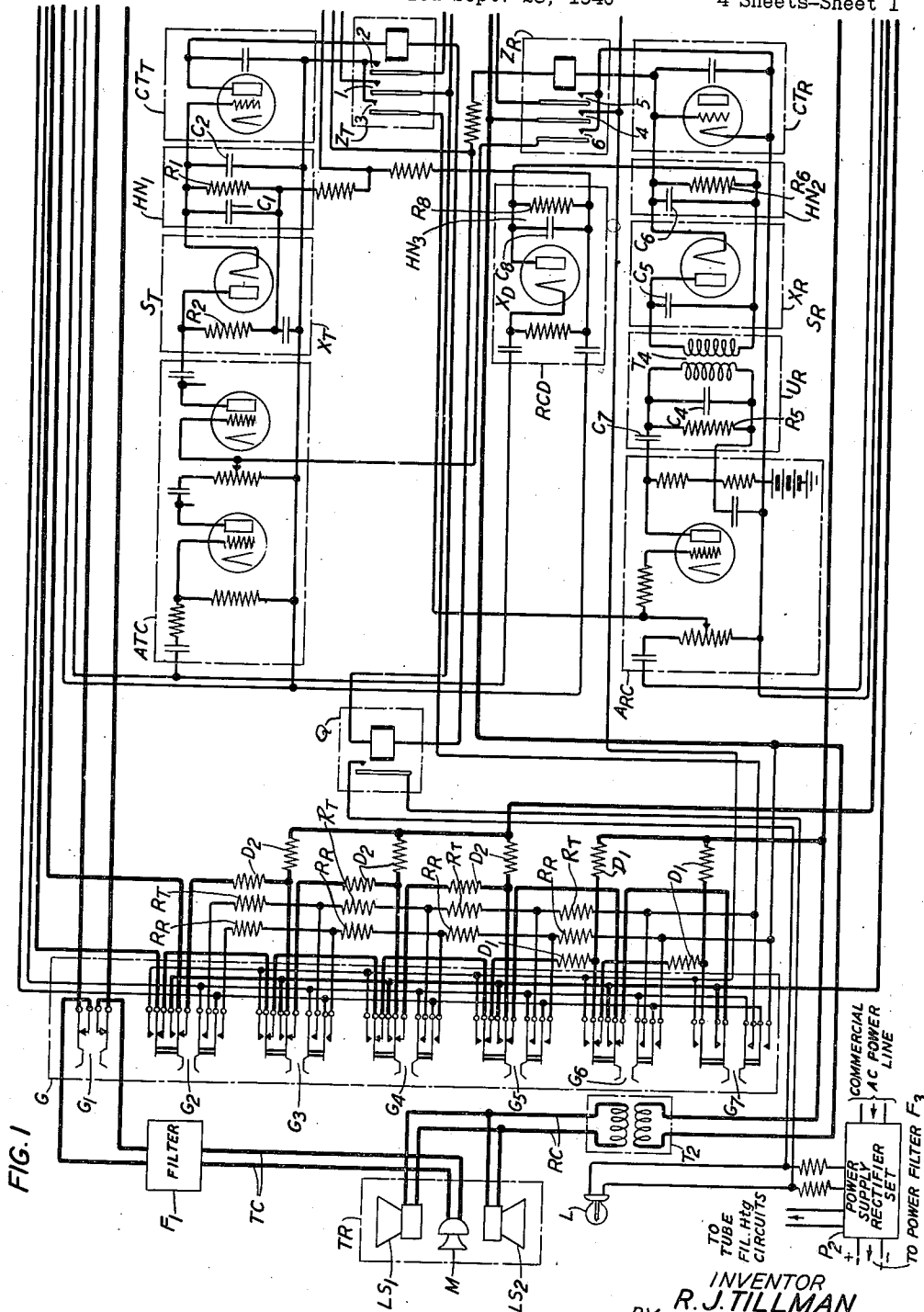
R. J. TILLMAN

2,269,565

COMMUNICATION SYSTEM

Filed Sept. 28, 1940

4 Sheets-Sheet 1



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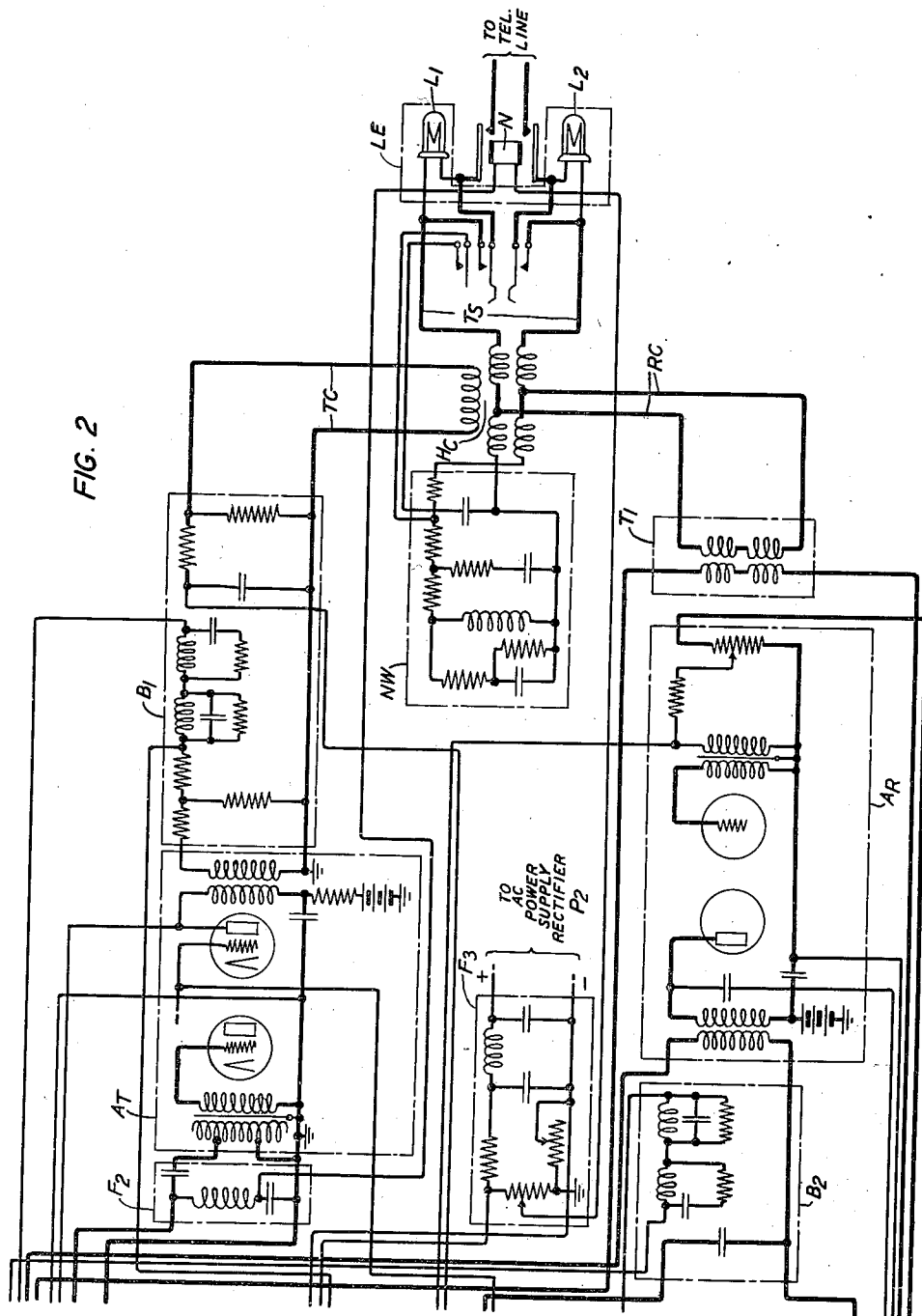
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COMMUNICATION SYSTEM

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4 Sheets-Sheet 2



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4 Sheets-Sheet 3

FIG. 3

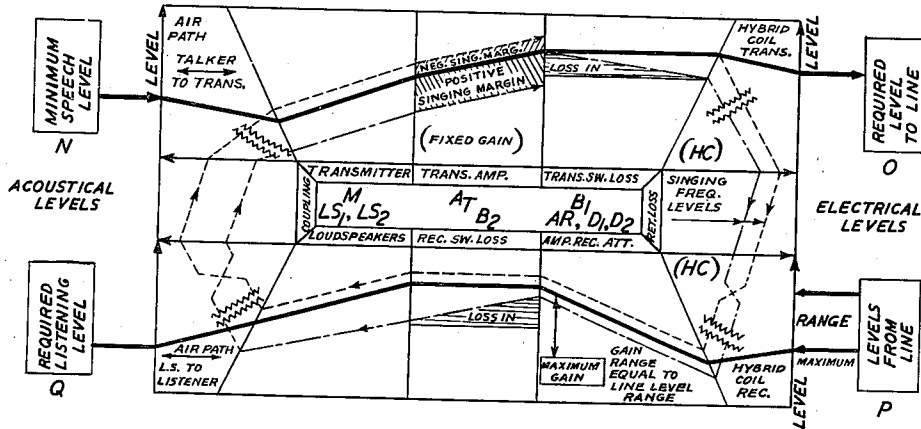


FIG. 4

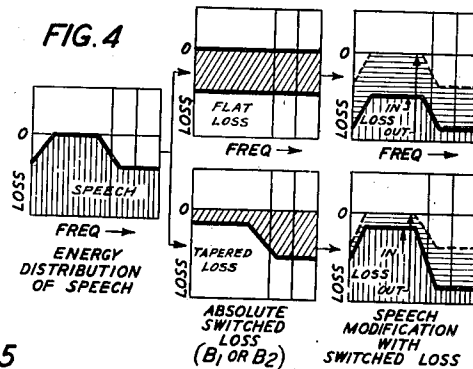
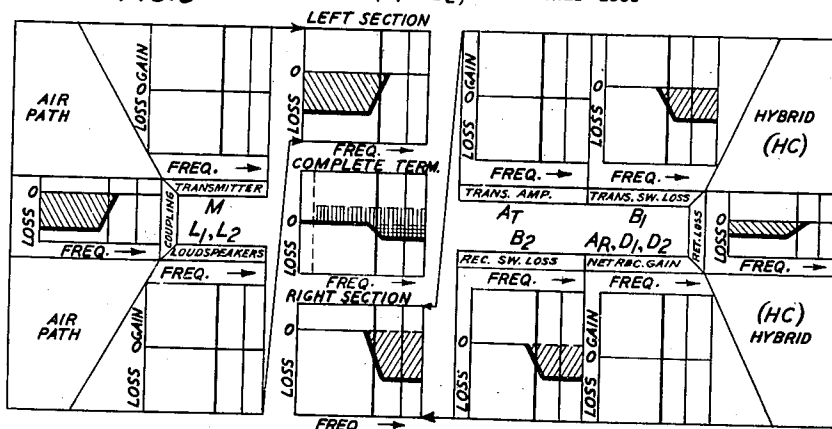


FIG. 5



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4 Sheets-Sheet 4

FIG. 6

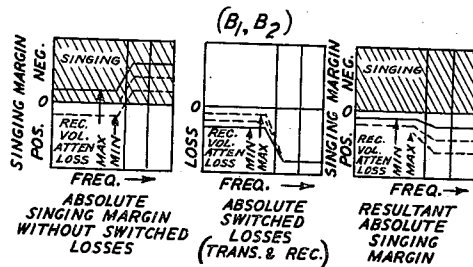


FIG. 7

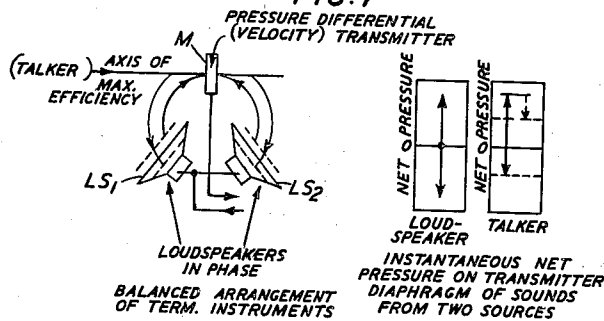
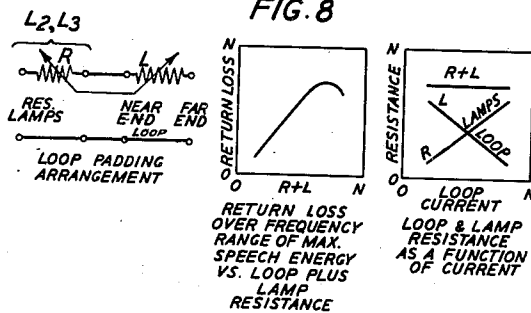


FIG. 8



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UNITED STATES PATENT OFFICE

2,269,565

COMMUNICATION SYSTEM

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Application September 28, 1940, Serial No. 358,785

25 Claims. (Cl. 179—1)

The invention relates to communication systems and particularly to two-way communication systems and circuits for controlling transmission over such systems.

The invention is particularly applicable to, although not limited to, telephone systems employing distant-talking telephone transmitters and receivers of the loud-speaking type, as well as amplifiers, at the subscriber stations to enable individual telephone subscribers, or each person of different groups of persons gathered in conference at remotely located stations to converse with each other over an intervening line without the necessity of holding the receiver or being in close proximity to the transmitter or receiver. Such systems may employ at the subscriber stations switching circuits controlled by the voice currents of the speaker to automatically switch loss between the transmitting and receiving voice amplifying paths to control the direction of transmission, to provide a desired amount of amplification and to minimize the possibility of the setting up of a singing condition due to electrical and acoustic couplings between these paths.

An object of the invention is to improve the operation of systems of the above-described general types.

Another object of this invention is to improve the operation of a telephone set of the general type described above and to enable it to be connected to any telephone line in the same manner and interchangeably with an ordinary telephone set.

A related object is to select, relatively arrange and adjust manual and automatic devices for exercising different types of control on transmission at a station of a two-way telephone system so as to provide improved operation from the standpoint of quality and volume of transmission and singing prevention with economy of apparatus and space.

Another object is to enable two-way conversation between remotely located telephone subscribers or between the individuals in different groups of persons gathered in conference at two or more separate stations of a two-way telephone system, with a freedom of movement and facility approaching that obtainable in face-to-face conversation of individuals at one location.

Another object is to enable a subscriber at one station of a two-way telephone system to connect his telephone set with a telephone line, and to control the volume of signal transmission at

the station in accordance with his hearing requirements.

Another object is to automatically compensate for difference in the lengths or impedance characteristics of lines connected to a telephone set.

Another object is to automatically reduce side-tone in a telephone set.

The main objective realized by the device of the invention to be described in detail below is the provision at a reasonable cost of a compact, voice-operated, distant talking, loud-speaking telephone set, preferably operated from a commercial alternating current supply, for use with the ordinary line of a telephone subscriber, which, by not requiring the user to hold in his hand or otherwise approach the instrument within less than 2 feet, approximates, in ease of usage, the facility of normal direct conversation. This is accomplished with no effect on the proper operation of the telephone circuits and little or no penalty in the grade of transmission ordinarily obtained over such circuits. The device realizing the above objective meets the following general specifications:

1. Each component has been provided at the minimum cost which will give the required performance.

2. The talking and listening instruments are at a sufficient distance from the user so as to give him complete freedom of motion within a limited area.

3. The electrical volume level delivered to the telephone circuit by the transmitter element is consistent in both average value and range with normal telephone practice.

4. The received volume is sufficient to enable the user to hear as well or better than if he were using a regular telephone set.

5. Transmission quality degradation ordinarily introduced by voice-operated switches has been minimized.

6. The transmitting circuit has been connected to the telephone line terminals in such a manner as to minimize its effect on the receiving circuit.

7. The receiving circuit has been connected to the same telephone line terminals in such manner as to minimize its effect on the transmitting circuit.

8. Loud-speakers have been provided which will produce the desired sound level with a given amplifier output.

The preferred embodiment of the invention may be briefly described as a compact, economical, two-way telephone set adapted for use at one or more subscribers' stations of a two-way

telephone system, comprising a transmitting amplifying branch including a distant-talking telephone transmitter, and a receiving amplifying branch including loud-speaking telephone receivers, coupled by a hybrid transformer and associated balancing network to a two-wire line section adapted for connection to ordinary telephone lines; and associated voice-operated switching circuits for switching suitable losses between the transmitting and receiving branches, to provide directional control, the desired amplification and singing prevention, this set having the following special features:

1. To minimize the quality distortion inherent in loss switching, the frequency-loss characteristics of the acoustic and electrical couplings between the voice transmitting and receiving branches are made such as to provide minimum positive potential feedback (singing) in the frequency band at which the maximum energy of speech is located (approximately 100 to 1000 cycles) without affecting the frequency characteristics of the separate voice branches, in order to reduce the amount of loss necessary to be switched in this particular frequency band to prevent singing, and the resistance component of each switched loss pad is adjusted to that value which will provide adequate singing margin with a tolerable amount of quality distortion. To accomplish this

(a) The coupling between the microphone and the loud-speakers is designed to provide a high loss over the frequency range of maximum speech energy. This may be obtained by a special mounting and relative arrangement of loud-speaking receivers in the voice receiving branch and the transmitter in the voice transmitting branch, so that they are acoustically balanced with respect to each other over that frequency range.

(b) The electrical coupling between the connected telephone line and the transmitting and receiving voice branches of the telephone set is provided by using in combination with a hybrid transformer coupling the transmitting and receiving voice branches to the two-wire terminating line section, of a special balancing network and a loop resistance equalizer comprising elements having a non-linear current-resistance characteristic, connected in series with the terminating line section of the set, to provide by electrical balance relatively high magnitude and limited variation of return loss through the hybrid transformer over the frequency range of maximum speech energy for any one of different (length or impedance) subscribers' lines with which the set may be required to work.

(c) A special network is included in each voice branch, having similar shaped frequency-loss characteristics over the frequency range of maximum speech energy (100 to 1000 cycles), the combined insertion loss versus frequency characteristic of the two networks being the inverse of the frequency characteristic of the singing path before insertion of the networks, to provide an

equal margin against singing in the circular electroacoustic loop for all frequencies in the transmission range. Provision is made for complete removal of the insertion loss of the network in either voice branch by means of a voice-operated relay under control of speech energy in that branch. The distortion of the speech waves in the voice branch caused by removal of the network is a minimum since the insertion loss of the network is small over the frequency range of maximum speech energy. To enable the loss of each network to be adjusted to the proper value, it is made variable in magnitude by means of a resistance change under control of the user of the set as a correlative function of volume adjustment.

2. A circuit for desensitizing the receiving control of the voice-operated switching circuit as a function of the level produced by the talker at the input of the transmitting switching control so as to prevent false operation of the receiving switching relay when the transmitting voice branch is operated.

3. A two-part, multistep volume control attenuator in the receiving voice branch controlled by a multiple interlocking key switch to be operated by the telephone subscriber or user of the set to provide the required attenuation range of received speech volume but a smaller attenuation range of receiving control circuit sensitivity. Auxiliary features of this manual switch control are that it operates to change the insertion loss over the frequency range of maximum speech energy of each of the two switched loss networks in an equal amount inversely with change in loss of the receiving volume attenuator, and controls the connection of the telephone set to the selected telephone subscriber's loop.

Other objects and features will be brought out in the following detailed description of the invention in conjunction with the drawings in which:

Figs. 1 and 2, in combination, with Fig. 1 at the left show schematically a preferred modification of the telephone set of the invention; and

Figs. 3 to 8 are diagrams illustrating the principles involved and the characteristics of the component elements in the telephone set of the invention shown in Figs. 1 and 2.

The circuit of Figs. 1 and 2 includes a transmitting voice branch TC and a receiving voice branch RC coupled by the three-winding hybrid transformer HC and associated balancing network NW to the two-wire terminating section TS which is connected to the telephone line by operation of the relay N.

The transmitting voice branch TC comprises, reading from left to right, a telephone transmitter M, an anti-cohering filter F_1 which protects the transmitter carbon from switching transients, the transmitter power supply filter F_2 , the transmitting voice amplifier Ar preferably comprising two or more vacuum tube stages, and the shaped frequency-loss switching network B_1 , including the variable resistance elements R_T , the output of which is connected to a winding of the hybrid transformer HC.

The receiving voice branch RC comprises, reading from right to left, a transformer T_1 having its primary winding connected across the mid-

points of the line windings of hybrid transformer HC, functioning to provide a path for the direct current flow through the telephone line and ballast lamps L_1 , L_2 when relay N is operated, a variable resistance volume attenuator D_2 having its input connected to the secondary winding of transformer T_1 , the receiving voice amplifier A_R preferably comprising two or more vacuum tube stages, a second variable resistance volume attenuator D_1 and the shaped frequency-loss switching network B_2 including the variable resistance elements R_R , having its output coupled to a loud-speaking telephone receiver comprising two parallel-connected loud-speakers LS_1 and LS_2 , through the impedance matching transformer T_2 .

The voice-operated switching arrangement provided for switching losses between the transmitting circuit TC and RC to provide directional control of the set while preventing singing and suppressing echoes and noise, includes the transmitting switching control branch S_T and a receiving switching control branch S_R .

The transmitting switching branch S_T includes an adjustable gain alternating current amplifier A_{TC} consisting of two or more vacuum tube stages, having its input connected across the plate-cathode circuit of the last vacuum stage of the transmitting voice amplifier A_T , followed by a rectifier X_T , a voltage storing or hang-over network HN_1 , a three-electrode control vacuum tube CT_T , and the transmitting switching relay Z_T and the indicator lamp control relay Q having their operating windings connected in series in the cathode-anode circuit of the tube CT_T .

The receiving switching branch S_R includes an adjustable gain receiving control amplifier A_{RC} consisting of one or more vacuum tube stages, having its input connected across the plate-cathode circuit of the last stage of the receiving voice amplifier A_R , rectifier X_R connected to the output of the amplifier A_{RC} through a frequency weighting network U_R , a voltage storing or hang-over network HN_2 connected to the output of the rectifier X_R followed by a three-electrode control vacuum tube CT_R and a switching relay Z_R having its operating winding connected to the plate-cathode circuit of tube CT_R .

The voice-operated switching circuit also includes a desensitizing circuit RCD for the receiving switching circuit S_R , consisting of a rectifier X_D having its input connected across the input of the transmitting control amplifier A_{TC} , and a voltage storing or hang-over network HN_3 in the output of that rectifier, connected in series with the hang-over network HN_2 in the control grid circuit of the relay controlling tube CT_R in the receiving switching control circuit S_R .

A loop resistance equalizer LE in the terminating two-wire section TS of the set comprises the ballast lamps L_2 and L_3 having suitable non-linear resistance-current characteristics, in series with the line wires.

A manual switch G comprising a series of interlocking keys G_1 to G_7 is provided for enabling the subscriber or other operator at the subscriber's station to control the energization of the telephone set, its connection to the selected telephone line, and the adjustment of the amount of resistance in the receiving attenuators D_1 and D_2 and in the loss networks B_1 and B_2 in the manner to be described below.

The telephone set as illustrated is operated from a commercial alternating current supply although it may be readily adjusted for operation

also from a direct current supply. The low-voltage alternating current power for energizing the indicator lamp L_1 and for heating the filaments of the various vacuum tubes is obtained directly from a power supply set P_2 comprising the usual alternating current rectifier and power transformer, supplied from a commercial alternating current line, and the power for energizing the transmitter T, the switching relay N, and for supplying the plate and grid biasing potentials for the vacuum tubes in the amplifiers and rectifiers of the set is obtained from that set P_2 through the power supply filter F_3 or that filter in combination with the power supply filter F_2 .

The transmitter M is preferably a carbon microphone of the pressure differential type with a bi-directional diaphragm, mounted in a baffle, as disclosed in the copending application of W. D. Goodale, Jr., A. Herckmans and R. J. Tillman, Serial No. 352,692, filed August 15, 1940. This microphone M and the two parallel-connected moving coil loud-speakers LS_1 and LS_2 in the assembly TR, are preferably mounted and relatively arranged in the manner disclosed in the aforementioned copending application and illustrated diagrammatically in Fig. 7 of this application, so that they are acoustically balanced with respect to each other over the frequency range of maximum speech energy, providing a high coupling loss over that frequency range between the microphone and the loudspeakers.

The small low-frequency loss network B_1 in the transmitting circuit TC and the small low frequency loss network B_2 in the receiving circuit RC are identical. Each may comprise the particular arrangement of inductance, capacitance and resistance elements shown, or equivalent arrangements, with suitable relative values for these elements to provide a frequency-loss characteristic for the network such as to give an insertion loss over the frequency range of maximum speech energy which is low with respect to the rest of the speech range in accordance with the acoustic and electric couplings between the voice transmitting and receiving branches. Each network is variable in resistance in accordance with the number of units of resistance R_T or R_R , respectively connected in the network by operation of the keys of the manual switch G by the telephone subscriber, to provide the proper amount of anti-singing loss depending on transmission conditions in the manner which will be described later. With the particular transmission elements used in the experimental model of this telephone set, the maximum insertion loss provided by each network B_1 or B_2 was in the order of 10 decibels at low frequencies.

The particular arrangement of inductance, capacitance and resistance elements in the special balancing network NW, and their relative values, and the values of the series variable resistance (ballast) lamps L_2 and L_3 in the loop equalizer LE in the terminating section LS of the telephone set, were selected with respect to the particular hybrid coil network HC used, to automatically provide the required electrical balance to give a relatively high magnitude and limited variation of return loss through the hybrid coil over the frequency range of maximum speech energy, for any telephone line with which the set may be required to work.

The telephone sets at other connected stations may be of the general type described above or may be standard telephone sets without voice-operated switching apparatus.

The operation of the telephone set of Figs. 1 and 2 will now be described.

When it is desired to use this set, the telephone subscriber or other user automatically releases key G_1 of his multiple key-controlled switch G by manual operation of any of keys G_2 to G_7 to cause suitable energizing power to be supplied to the microphone M (the filaments and other electrodes of the various vacuum tubes of the set being already energized from the attenuating current supply), and to the switching relay N . The signal lamp L_1 will then be lighted, and the switching relay N will operate to connect the terminating section TS of the telephone set to a telephone line over which the connection to the distant party or parties is established in the usual manner.

With no one talking in either direction over the set, the shaped frequency-loss networks B_1 and B_2 are both effective in the transmitting circuit TC and the receiving circuit RC , respectively, and the resistance values of these networks and that of the attenuation networks D_1 and D_2 in the receiving circuit RC depend upon which of keys G_2 to G_7 are operated. Whatever this operation, the loss in the electroacoustic loop provided by the set will be such as to prevent the establishment of positive feedback or singing. When conversation begins the subscriber may again operate any key G_2 to G_7 of the manual switch G depending on his receiving volume requirement, which automatically adjusts the amount of resistance provided by the resistance elements R_T and R_R to control the low-frequency loss value of networks B_1 and B_2 to provide the minimum amount of low-frequency switched loss consistent with singing prevention.

When the user of the set starts to speak, his speech currents will be transmitted from the microphone T over the transmitting circuit TC through the anti-cohering filter F_1 and will be amplified by the transmitting amplifier A_T . A portion of the amplified speech currents in the output of that amplifier will be diverted into the transmitting switch control S_T in which it will be divided between the input of the amplifier A_{TC} in the main branch and the input of the receiving control desensitizing branch RCD .

The portion of the speech signals applied to the input of amplifier A_{TC} will be amplified thereby and will be rectified by the half wave rectifier X_T . The rectified voltage produces a variable direct current bias on the control grid of tube CT_R across the parallel resistance R_1 and condenser C_1 of hang-over circuit HN_1 . The magnitude of this bias is initially adjusted by means of the adjustable gain control of amplifier A_{TC} to cause the operation of the transmitting switching relay Z_T by the plate current of tube C_T at a predetermined speech level. The polarity of this variable bias is in opposition to the fixed bias on the control grid of tube CT_R which ordinarily permits only a slight current to flow through the tube and the windings of the transmitting switching relay Z_T and the indicator control relay Q in series in its output which is not sufficient to operate these relays. As the variable bias changes in magnitude due to increasing speech level at the input of the control amplifier A_{TC} , the increasing flow of current through the relay control tube C_{TC} and the winding of switching relays Z_T and Q causes relay Z_T to operate to close its relay contacts 1, 2 and 3, and relay Q to operate to short-circuit indicator lamp L_1 , extinguishing it and thus indicating to the

talker that the transmitting switching control S_T is operating properly.

The closing of contacts 1 of relay Z_T effectively short-circuits the shaped frequency-loss network B_1 in the transmitting voice path TC , allowing the main portion of amplified speech energy in the output of transmitting amplifier A_T , to be transmitted over the outgoing portion of transmitting circuit TC through hybrid coil HC and loop equalizer LE to the connected telephone line with little additional attenuation. The closing of contacts 2 of relay Z_T disables the receiving amplifier A_R in receiving circuit RC by connecting one side of its input line to ground. The closing of relay contacts 3 operates to bring the potential of the control grid of the amplifier A_{RC} to ground, thus disabling the receiver control circuit S_R in its input. The sensitivity and therefore the time constants of the relay contacts 1, 2 and 3 of the transmitting switching relay Z_T are made such that the latter two functions are performed before the removal of the loss B_1 from the transmitting voice path TC .

When the subscriber at the station ceases talking or the level of his speech currents at the input to the transmitting control circuit S_T decreases below a given minimum value, the variable bias applied to the control tube CT_R in the circuit S_T is maintained sufficiently high to continue the closure of the contacts of relay Z_T for a desired hang-over time interval determined by the values of the resistance and capacitance elements R_1 and C_1 in the hang-over network HN_1 , and when relay Z_T releases the time constants of the relay contacts are such as to cause the network B_1 to be reintroduced into the transmitting circuit TC before the receiving circuit RC is again enabled.

The use of the desensitizing circuit RCD was found to be necessary because of the use of the small low-frequency switched loss pads which permit the part of the transmitted speech energy passing through the hybrid coil HC to the input of the receiving switching control S_R , due to residual unbalance, to be at a rather high level, higher for instance than the lowest line level at which this control is supposed to operate. Since the transmitting switching control S_T , which disables the receiving control S_R , cannot be made too sensitive if it is not to be operated by room noise, the unbalance currents passing into the receiving circuit RC may cause the receiving control S_R to falsely operate to disable the transmitting side when the set is being used for transmitting. The circuit RCD prevents this by causing the receiving control S_R to be desensitized in proportion to the talking level at the input of the transmitting control S_T so as to prevent operation of the receiving switching control S_R when the transmitting circuit TC is transmitting signals. The time constants of the circuit elements in the rectifier and associated hang-over network of the circuit RCD are selected so that the circuit has a fast attack time, faster than that of the receiving switching control and less hold-over time than the latter control. The circuit RCD operates as follows:

Like the similar relay control tube CT_R in the transmitting control S_T , the control tube CT_R in the receiving control S_R has a fixed biasing voltage applied to its control grid which normally prevents sufficient plate current flow through the winding of the receiving switching relay Z_R to operate the relay contacts. This bias is normally overcome by the opposing variable bias

produced on the control grid of that tube by hang-over network HN_2 in response to the output of rectifier X_b , varying as a function of the speech level at the input of the receiving control S_r . The fixed bias on the relay control tube CT_r which must be overcome to produce sufficient current flow to the winding of relay Z_r to operate it, represents margin against operation of the relay contacts.

The portion of the talker's speech currents diverted to the desensitizing circuit RCD is rectified by the half wave rectifier X_b and the rectified voltage varying in accordance with the talker's speech currents is applied across the resistance R_3 and parallel condenser C_3 of the hang-over network HN_2 to produce a third bias on the control grid of tube CT_r . This third (variable) bias is in series with the other two biases, and is poled so as to aid the fixed bias and oppose the other variable bias supplied by hang-over network HN_2 . By proper selection of the values of the elements in the desensitizing circuit RCD , the magnitude of this third bias produced by the desensitizing circuit RCD on the control grid of the tube CT_r is made equal to the variable bias applied thereto from the receiving control S_r which would ordinarily cause false operation due to speech levels from the transmitter passing through the unbalance of the hybrid coil for the case where the switch G is operated to produce "high" received speech volume. As a result, the opposing varying biases cancel one another, leaving the margin against operation of switching control S_r originally provided by the normal fixed bias so as to maintain the receiving switching relay Z_r unoperated while the local subscriber is talking. The desensitizing circuit makes it possible to maintain suitable operation of the terminal as a whole with a smaller low-frequency switched loss than would otherwise be necessary. This reduction in the switching loss over the frequency range of maximum speech energy is an important asset for when such loss is excessive, its switching in and out gives rise to undesirable transient voltages in the circuit and a consequent loss in intelligibility. A reduction in the magnitude of the switched loss over this range reduces such undesirable effects. The use of the circuit RCD also makes it possible to use a higher sensitivity for the receiving switching control S_r so as to enable its operation on lower level signals incoming from the line.

The portion of the talker's voice energy transmitted from the output of the transmitting voice circuit TC to the input of the receiving voice circuit RC , due to any unbalance in the hybrid coil HC and associated balancing network NW , will not reach the loud-speaking receivers LS_1 and LS_2 because of the previous blocking of the receiving voice amplifier A_r by operation of the transmitting switching control S_r in the manner which has been described.

Now, let it be assumed that when the local subscriber ceases talking or pauses for a sufficient time interval to release the transmitting switching control S_r speech currents are received over the connected telephone line from a distant telephone subscriber and pass through the hybrid transformer HC to the receiving voice branch RC .

The resistance of the non-linear ballast lamps L_1 and L_2 in the loop equalizer LE which varies directly with the relatively high direct current flowing through a telephone loop but is not affected by the relatively weaker speech currents, becomes stable at a value determined by the

electrical length of a given loop and the associated telephone line battery (not shown) the instant the set is connected to a telephone loop and thus automatically adjusts the balance of the hybrid coil set so as to compensate for differences in the length of the connected subscriber's line from the average length line for which the compromise balancing network NW has been designed, so as to maintain the return loss through the hybrid transformer HC high and substantially constant over the frequency range of maximum speech energy. This automatic balance, then, is present for any condition of transmitting or receiving and is independent of speech currents.

An alternative use for the combination of the hybrid transformer balancing network and equalizing ballast lamps is to automatically reduce the volume of side-tone in the telephone set.

The received voice currents will be transmitted through and attenuated in the volume attenuator D_2 except in the maximum volume condition and, the receiving circuit RC being unblocked due to the unoperated condition of the transmitting switching control S_r , will be amplified in the receiving speech amplifier A_r . The amplified voice currents will then be divided between the input of the receiving volume attenuator D_1 in the receiving voice branch RC and the input of the receiving switching control S_r .

The portion of the received voice currents transmitted into the receiving switching control S_r will be impressed on the input of the variable gain amplifier A_{RC} and will be amplified thereby in accordance with its gain setting. The amplified waves in the output of the amplifier A_{RC} will then pass through the frequency weighting or shaping network U_r to the rectifier X_r . The network U_r comprises a transformer T_3 , which transformer is tuned by the condensers C_4 and C_5 connected across its primary and secondary windings, respectively, to a frequency approximately in that portion of the speech range of highest power, that is, from 100 to 1000 cycles. This tuning is rendered rather flat by the resistance elements in the circuit, such as resistance R_5 . The circuit thus discriminates against the extreme low and high frequencies of circuit noises in the telephone band of transmission and produces a favorable signal-to-noise ratio for the switching control S_r for the higher energy telephone speech frequencies. Additional low frequency discrimination is attained by the use of the series condenser C_7 .

The speech waves in the output of the shaping network U_r are rectified by the rectifier circuit X_r consisting of a half-wave rectifier tube, the resistance R_6 and parallel condenser C_6 . The direct current voltage thereby developed across the resistance R_6 , the desensitizer circuit RCD being unoperated due to the absence of applied transmitted speech and due to the large coupling loss between loud-speaker and transmitter, serves to overcome the fixed bias on the control grid of the receiving control tube CT_r causing operation of the receiving switching relay Z_r by the tube output current.

The operation of relay Z_r to close relay contacts 4 effectively short-circuits the shaped frequency-loss network B_2 thereby removing the anti-singing loss from the voice receiving branch RC . The closing of switch contacts 5 effectively disables the voice transmitting side TC of the set by connecting the control grid of the last vacuum tube stage of the transmitting amplifier A_t to ground. The closing of the switch contacts 6 connects the control grid of the last tube

of the transmitting control amplifier A_{TC} to ground, thus disabling the transmitting switching control S_T ; contacts 5 and 6 functioning before contact 4.

The amplified speech energy in the output of the receiving amplifier A_R will be transmitted through and attenuated in volume attenuator D_1 except on the higher volume conditions and, the shaped frequency-loss network B_2 having been effectively eliminated, will then be transmitted with little attenuation through transformer T_2 to the loud-speakers LS_1 and LS_2 and will be heard by the local subscriber. The local subscriber, then, by depressing the keys G_2 to G_7 consecutively may add an increasing number of units of resistance first in the volume attenuator D_2 and then in the volume attenuator D_1 to reduce the acoustic level of the received speech, or by depressing the same keys in reverse order may progressively cut out resistance units first in volume attenuator D_1 and then in volume attenuator D_2 to increase the acoustic level of the received speech, in accordance with his hearing requirements and the level of incoming speech on the telephone line. This arrangement provides in addition to the required attenuation range of the received speech volume, a smaller attenuation range of sensitivity of the receiving switching control S_R , due to the fact that only the volume attenuator D_2 is effective in varying the level delivered to the receiving switching control whereas both volume attenuators D_1 and D_2 are effective in the receiving voice branch RC . This limitation of reduction in sensitivity of the receiving switching control S_R as the received volume is reduced, provides higher sensitivity of the control circuit with respect to high incoming speech levels giving a better performance of the set on the higher speech levels which will probably be typical of the majority of calls.

The operation of the keys G_2 to G_7 by the local subscriber ostensibly to control volume provides in addition to a variation of the loss in the voice receiving circuit RC to provide proper control of the receiving speech volume and receiving switching control sensitivity, an inverse control of the amount of loss in the frequency range of maximum speech energy in the frequency-loss networks B_1 and B_2 . If the maximum available gain is not needed to provide adequate levels as is the case with the majority of calls, less loss may be switched with a resulting improvement in speech intelligibility. Therefore when the keys G_2 to G_7 are operated to step down the receiving volume (by increasing the amount of loss in the receiving voice path) they simultaneously operate to control the number of resistance units in the variable resistance portions R_T and R_R of the switching networks B_1 and B_2 in the transmitting and receiving voice paths, respectively, so as to reduce the amount of switched loss over the frequency range of interest, the loss values of the two loss networks being changed equally and in the same direction.

The diagrams of Figs. 3 to 8 with explanatory legends illustrate the special principles involved and the characteristics of the component elements of the two-way telephone set of the invention illustrated in Figs. 1 and 2 and described above.

Fig. 3 shows the required gains and losses in the two directions of transmission and the loud-speaker transmitter coupling loss and return loss through the hybrid coil in the form of a level diagram obtained with an experimental model of

the set. The heavy solid line from point N to point O shows that the gain which must be provided in the transmitting voice branch is a function of the required line level at point O , when a talker speaks just loudly enough above average room noise at point N to operate the transmitting switching control. The heavy line from point P to point Q illustrates the corresponding requirements for the receiving voice branch. In this case, the predetermined speech level depends on average room noise sound level, and sufficient gain must be available to deliver this speech level for the lowest incoming level from the telephone line at which the receiving switching control can discriminate between speech and average line noise. The two dashed lines which start from the output of the transmit amplifier and depart from the solid lines are for the case where both transmit and received switched losses are left in the circuit and for the case where both are omitted. These lines illustrate the need for adding losses to obtain a positive singing margin.

The diagrams of Fig. 4 show a comparison of the change in speech energy versus frequency caused by the insertion or removal of a loss shaped with frequency, as in the system of the invention, or of a loss constant with frequency. Where the singing path is so designed as to have minimum gain in the region of maximum speech energy and the switched loss is shaped accordingly, it will be seen from these diagrams that there is less change in the range of maximum speech energy than if a loss constant with frequency, whose magnitude is determined by the singing path gain at the singing frequency, is switched in and out of the circuit. Since the energy content of the speech is relatively less at the higher frequencies, the absolute magnitude of any transient induced by switching at those frequencies might be expected to be such as to cause little disturbance. It should also be pointed out that abrupt switching of loss at the lower frequencies has an annoying effect on the listener because of the change in loudness of the background room noise, and that this effect is minimized by restricting the magnitude of the loss switched at these frequencies.

The diagrams of Fig. 7 illustrate the functioning of the particular arrangement provided for reducing the acoustic coupling between the transmitting and receiving voice circuits in the system of the invention. As indicated, two moving coil loud-speakers and a carbon transmitter of the pressure differential type (with diaphragm accessible to sounds from front and rear) mounted in a baffle comprise this arrangement. The moving coils of the two loud-speakers are connected in parallel in such a way as to have the cones in phase as regards motion towards and away from the center line. The loud-speakers are symmetrically mounted with respect to the transmitter, and the axis through the center of the cone of each loud-speaker lies in the same plane as the axis perpendicular to the transmitter diaphragm which is also its axis of maximum efficiency for speech. In an experimental model of this arrangement which has been built and tested, the whole assembly (TR) is contained in a small cabinet with the plane of the face of each loud-speaker inclined at such an angle as to direct the sound from desk level upwards to the ears of the user. The baffle containing the transmitter is mounted at the top of the cabinet. The cabinet completely encloses the loud-speakers and contains sound-absorbing

material so that the loud-speakers radiate only from the outer surfaces of the cones. The method of acoustic balance is illustrated at the right of this figure. It is shown that due to the equal distance and phase of the loud-speakers with respect to the transmitter, no net pressure is developed on the transmitter diaphragm by the direct action of the loud-speakers. There is a variation in the net pressure developed with increasing frequency such that the net pressure on the transmitter diaphragm, while it is zero or low at low frequencies, increases to some extent with increasing frequency, giving a relative coupling loss of the shape shown at the left diagram of Fig. 5. As regards speech directed at the transmitter, there is a net pressure exerted on the diaphragm due to the difference in pressure on the front and rear. This net pressure decreases, of course, as the speaker moves off the central axis of the transmitter. There is a corresponding discrimination afforded against room noise of random incidence due to this pressure differential characteristic. It should be pointed out that the high coupling loss over the range of maximum speech energy frequencies as provided by this type of balance is desirable for the prevention of false operation of the transmitting switching control circuit due to direct sounds from the loud-speakers.

The diagrams of Fig. 8 illustrate the function of the loop resistance equalizer (LE in Fig. 2). The action of the variable resistance ballast lamps (L_2 and L_3) in this equalizer is to limit the range of loop resistances which might ordinarily be expected in practice to be connected to the set. At the expense of a small transmission loss added to the loss of a short loop, the equalizer by adding resistance to the given loop insures that in connection with the balancing network (element NW in Fig. 2), the return loss through the hybrid coil (element HC in Fig. 2) for any of the multiplicity of impedances connected to the central office end of the loop will be high over the range of maximum speech energy and of nearly the same magnitude as with a long loop. Of course, the transmission loss due to ballast lamp resistance is smaller for a long loop since the lamp resistance is a function of the current passing through it. As shown in Fig. 8, there is, with a balancing network designed specifically for the frequency range in question (such as NW in Fig. 2), a particular value of resistance between the telephone set and the varied impedance characteristics of the central office end of the telephone connection, which gives the optimum loss for all frequencies in the given range. In the curves to the right in Fig. 8 the complementary relationship between the loop resistance and lamp resistance as a function of current is shown. It is evident that the loop plus the ballast lamp resistance for any given loop will be held to a limited range.

The diagrams of Fig. 6 illustrate the function of the control switch (G in Fig. 1) which varies both the receiving volume and the switching network losses. As shown in the diagram to the left of the figure, the potential negative singing margin (the net gain in the closed electroacoustic loop without switched loss) varies with the amount of receiving volume attenuation necessary for proper reception in a given conversation. The low frequency loss portion of the two switched loss networks, as shown by the center diagram of Fig. 6, varies inversely with the receiving volume attenuator loss. As described

above, this is accomplished by varying the amount of the resistance R_T and R_R in the networks B_1 and B_2 , respectively, by suitable operation of the common switch control G. The latter networks are symmetrical and their resistance values are variable in an equal amount. The effect of this variation is to decrease the energy change due to switching at the frequencies of maximum speech energy, as the receiving speech is decreased for calls having higher incoming level. As indicated in the diagram at the right of Fig. 6, the switched losses are decreased in smaller increments than the receiving attenuator losses are increased. The differential provided is a compromise between the desirability of decreasing the switched loss as the receiving attenuator is varied for minimum attenuation, and the provision of some additional singing margin for the stronger volume calls which are less apt to provide smooth impedances at the near-end central office, because there is usually less trunk involved. It will be noted that the singing margin is greater at the higher frequencies for any condition of the common control G, and that the increment of additional singing margin added at these frequencies is equal to the increment of loss inserted by the receiving volume attenuators. This results because the shaped loss networks B_1 and B_2 are simpler in construction if only the low frequency loss is changed by varying the amount of resistance in the resistance element, because the switching of loss at the high frequencies is believed to produce little distortion and also since the return loss is not controlled at these frequencies.

A telephone set having circuit elements substantially as disclosed in Figs. 1 and 2 and described above, has been built and tested. Each item of apparatus on this set was selected with the ultimate cost in view and there is none which is inherently expensive. The set consists of two parts, one a small desk mounting containing the microphone, loud-speakers and volume control, and the other apparatus being contained in a cabinet approximately 1 cubic foot in volume, which may be located at some distance from the desk set. The tests which have been made on this set show that it provides transmission substantially equivalent to that provided by the ordinary telephone set and therefore is not limited as to circuit length. The talking and listening distances are such that convenience of conversation and freedom of motion are provided, and satisfactory operation is maintained over the range of noise levels that are likely to be encountered in private offices.

A later model of the telephone set which has been constructed and tested differs from that which has been illustrated and described mainly in the addition of a control circuit expander and the use of negative feedback on the control amplifier, in the transmitting switching control Sr, as disclosed in the copending application of H. W. Augustadt, Serial No. 351,869, filed August 8, 1940. The use of the shunt feedback on the control circuit amplifier decreases the attack time of the transmitting switching relays somewhat and the use of the expander provides a better signal-to-noise ratio in cases where room noise level is high and reduces the range of input signal levels over which the hang-over time varies with input level, these additions improving the operation of the set to some extent.

Another feature which may be incorporated in the telephone set of the invention is the use

of negative feedback in connection with the voice amplifier in the transmitting voice path or in the receiving voice path or both, to stabilize its voltage output so as to provide in addition to improvement from the standpoint of reducing distortion in the transmitted voice signals, the prevention of variation in the input of the associated voice operated switching circuit with variation in the impedance of the load circuit connected to the voice path with removal of loss from that path by the switching circuit, thereby decreasing the chance of false operation or singing, as disclosed in the copending patent application of H. W. Augustadt, Serial No. 285,042, filed July 18, 1939, which issued as Patent 2,214,804 on Sept. 17, 1940.

Although the telephone set of the invention was primarily devised for use on the telephone subscriber's premises as a desk set, it is apparent that it is applicable as well for use in telephone pay stations in which case the microphone, loudspeakers and control means arranged as described above, would be disposed in a telephone booth in a suitable manner and the amplifier and auxiliary equipment mounted inside or outside the booth and connected to a telephone line. Preferably, suitable means would be provided for controlling the acoustic conditions inside the booth, and the set would be combined with a coin collector or any other standard equipment required to provide the telephone service, in any suitable manner.

The devices described herein may also be used in connection with other types of instruments and circuits in which a means is required for the suppression of side-tone or singing. For example, they are suitable for use in universal telephone line service, announcing, intercommunication or other direct wire service, or in radio telephone service. They may be used with any type of two-way transmission medium, such as two and four-wire telephone circuits. Other modifications of the circuits illustrated and described which are within the spirit and scope of the invention will occur to persons skilled in the art.

What is claimed is:

1. A station for a two-way telephone system including a plurality of stations connected by a wave transmission medium, comprising two circuit branches each including an electroacoustic transducer operating respectively as a telephone transmitter and a telephone receiver, connected to said medium, voice-operated control circuits respectively controlled from a different one of said branch circuits for controlling the transmission efficiency of said branch circuits in such manner as to provide directional control of voice signal transmission at the station, and means to minimize voice signal quality impairment due to the changes in transmission efficiency of said branch circuits in providing the directional control comprising means to make the transmission efficiency changes relatively smaller over the frequency range of maximum speech energy than over the remainder of the speech frequency range.

2. The station of claim 1, in which the last-mentioned means provides the recited result without impeding transmission over the circuit branch transmitting signals.

3. The station of claim 1, in which said voice-operated control circuits provide the desired directional control by switching out a normal anti-singing loss in the branch circuit transmitting

signals and disabling the other branch circuit, and the last-mentioned means comprises means for making the loss-frequency characteristics of the anti-singing loss switched such that it normally provides an insertion loss which is relatively less over the frequency range of maximum speech energy than over the rest of the speech frequency range.

4. A two-way communication system comprising a plurality of stations connected by a two-way transmission medium, at least one of said stations comprising two circuit branches each terminated in an electroacoustic transducer respectively operating as a signal transmitter and a receiver, and connected to said medium, and means to reduce the amount of disturbing energy transmitted between the two transducers over said circuit branches comprising a common coupling means between said circuit branches and said medium providing a high loss between the branches over the frequency range of maximum energy in the communication signals.

5. The system of claim 4, in which said common coupling means comprising a hybrid transformer, an associated line balancing network and automatically variable resistance elements providing in combination the required high loss between said branches over the frequency range of maximum signal energy.

6. The system of claim 4, in which said common coupling means comprises a hybrid transformer coupling said branches to each other and to said transmission medium, an associated line balancing network and an automatic line-length equalizing device of such relative characteristics as to provide between said circuit branches the desired high loss over said frequency range of maximum energy in the communication signals, enabling a relatively smaller change to be made in the transmission efficiency of a circuit branch over that frequency range where an increase in efficiency of that branch is required in signal transmission.

7. The station of claim 1, in which said transmission medium is a two-way transmission line and said two circuit branches are coupled in common to said line.

8. The station of claim 1, in which said two-way transmission medium comprises two oppositely-directed transmission circuits, the transmitting circuit branch being connected to the one of the latter circuits transmitting in the same direction, and the receiving circuit branch being connected to the one of the latter circuits transmitting in the opposite direction.

9. The station of claim 1, in which said voice signal quality impairment is further minimized by auxiliary means for simultaneously reducing the magnitude of a change in transmission efficiency of one or both circuit branches in the frequency range of maximum speech energy produced by operation of a voice-operated control circuit.

10. A station for a two-way telephone transmission system including a plurality of stations connected by a wave transmission medium, comprising a transmitting circuit branch including a telephone transmitter, and a receiving circuit branch including a receiver, connected to said medium, voice operated control circuits for controlling the transmission efficiencies of the two circuit branches to provide directional control of signal transmission therein and auxiliary means to provide optimum relative efficiency of said circuit branches to improve the quality of speech

signal transmission over the system comprising a common control for effecting a desired magnitude of change in the transmitting efficiencies of one or both circuit branches with change of the efficiencies of said voice-operated control circuits.

11. A telephone set comprising a voice transmitting amplifying branch including a distant-talking telephone transmitter, a voice receiving amplifying branch including a loud-speaking telephone receiver, a two-way terminating circuit adapted for connection to a selected telephone line, common means for electrically coupling said transmitting branch and said receiving branch in transmission relation with said terminating circuit, means providing a normal loss in each of said voice branches sufficient to prevent singing in said set in the absence of voice signal transmission over either branch, a voice-operated switching device connected to each voice branch, responsive to voice signal transmission in the connected branch, when it is operative, to switch loss out of that branch to provide the desired transmission gain, and to disable the other voice branch and the switching device connected thereto in order to directionally control signal transmission, suppress echoes and prevent singing and false switching, and means to improve the operation of said set comprising means to make the frequency-loss characteristics of the losses switched, and of the acoustic and electrical couplings between said transmitting voice branch and said receiving voice branch such as to reduce to a low value positive potential feedback at the frequencies of maximum speech energy in the electroacoustic singing loop formed by said voice transmitting and voice receiving branches and the couplings therebetween, without affecting the frequency characteristics of the separate voice branches.

12. A telephone set comprising a voice transmitting branch including a distant-talking telephone transmitter and a one-way amplifier, a voice receiving branch including a loud-speaking telephone receiver and a one-way amplifier, a two-way terminating circuit adapted for connection to a selected telephone line, common means electrically coupling said voice transmitting branch and said voice receiving branch to said terminating circuit, loss networks respectively connected in said voice transmitting branch and said voice receiving branch, which, in the absence of voice transmission over either branch, provide equal losses therein sufficient to prevent singing around the electroacoustic loop formed by the two voice branches, voice-operated switching circuits respectively connected to said voice transmitting and said voice receiving branch, responsive to voice signal transmission in the connected voice branch, when it is operative, to switch out the loss network in that branch to provide the desired transmission gain, and to disable the other voice branch and the switching circuit connected thereto to control the direction of transmission and to prevent singing and false switching, and means to improve the operation of the set from the stand-point of transmission quality and singing prevention, comprising means to make the acoustic coupling and said electrical coupling between the voice transmitting and receiving branches respectively provide a large transmission loss in the frequency range of maximum speech energy, and means to adjust the loss in said frequency range of said loss networks to the minimum values which will pro-

vide adequate singing margin with quality distortion within a tolerable value.

13. The telephone set of claim 11, in which the desired characteristics are attained by employing in each voice branch a network with a shaped frequency-loss characteristic providing an insertion loss over the frequency range of maximum speech energy low with respect to the rest of the voice frequency range, and variable in magnitude by means of a resistance change, the loss network in each voice branch being effectively removed by operation of the voice-operated switching device connected to that voice branch, the maximum amount of loss provided by each loss network at low frequencies being in the order of ten decibels or less, and the resistance of each loss network being adjusted to the value which will provide adequate singing margin with a tolerable amount of quality distortion, and by employing in said electrical coupling a hybrid transformer with an associated line balancing network and a loop equalizer in said terminating circuit, providing in combination a relatively high magnitude and limited variation of return loss through said hybrid transformer between said voice transmitting and receiving branches over the frequency range of maximum speech energy for any telephone line on which the set may be required to work.

14. The telephone set of claim 12 in which said loss networks provide a smaller loss and said acoustic and electrical couplings a larger loss in the frequency range of 100 to 1000 cycles than they do to frequencies outside that range.

15. The system of claim 12 in which said common electrical coupling comprises a balanced bridge consisting of a hybrid coil and associated balancing network, said terminating circuit includes an equalizer of series elements having a non-linear current-resistance characteristic, the frequency-loss characteristics of said balancing network being selected to balance the average telephone line connected to said terminating circuit, and the varying resistance of said series elements with direct current from the line being such as to adjust the balance of said bridge, so as to adjust the balance of said bridge, so as to insure a high magnitude and limited variation of return loss through said hybrid coil between said voice transmitting and voice receiving branches over said frequency range of maximum speech energy for any one of a range of telephone lines to which the set may be connected.

16. The telephone set of claim 12 in which the voice-operated switching circuit connected to the voice transmitting branch includes a portion responsive to the applied voice energy to reduce the sensitivity of the voice-operated switching circuit connected to the receiving voice branch, in proportion to the increase in amplitude level of said applied voice energy, so as to prevent false operation of the latter switching circuit by signal echoes of a level higher than the lowest signal levels at which that switching circuit is designed to operate, while said voice transmitting branch is transmitting signals.

17. In combination with a two-way telephone system including oppositely-directed, one-way voice transmission paths and voice-operated switching circuits each including an amplifier preceded by a rectifier connected to each one-way path, operatively responsive to applied telephone signals to increase the transmission efficiency of that path and to disable the other voice

path and the connected switching circuit, an auxiliary control circuit operating to reduce the sensitivity of the amplifier in at least one switching circuit as a function of the signal amplitude level produced by a talker at the input of the other switching circuit, in order to prevent false operation of said one switching circuit by speech energy transmitted between said paths.

18. The telephone set of claim 11 in which said voice receiving branch includes volume control means comprising two or more variable attenuators so located and controlled as to produce a desired attenuation range of received speech signals, but a smaller attenuation range of sensitivity of the switching device connected to said voice receiving branch, providing improved performance of the set for higher level received signals.

19. In combination in a two-way telephone system, two oppositely directed one-way signal transmission paths, a voice-operated switching device connected to each path, responsive to voice signal transmission therein, in the absence of prior voice signal transmission in the other path, to increase the transmitting efficiency of the first path and to disable said other path, so as to directionally control signal transmission in said system while suppressing echoes and preventing singing, volume control means including two or more variable attenuators in at least one of said signal transmission paths, so located and controlled as to produce a desired attenuation range of transmitted speech signals in that path and a smaller attenuation range of sensitivity of the connected voice-operated device.

20. A telephone set in accordance with claim 12, in combination with manual means operated by the local subscriber for varying the attenuation in the voice receiving branch to control the acoustic volume level produced at the loudspeaking receiver, and for producing simultaneously an equal change in the resistance values of the two loss networks in the voice transmitting and receiving branches which is the inverse of the change in attenuation produced in the voice receiving branch.

21. A telephone set in accordance with claim 12 in combination with a two-part multi-step volume control attenuator in the receiving voice branch one part on each side of the receiving switching circuit input, and an interlocking key manual switch controlled by the local telephone subscriber for simultaneously controlling the adjustment of said attenuator so as to produce a desired attenuation range of received signal volume and a smaller attenuation range of receiving switching circuit sensitivity and the adjustment of the resistance of said loss networks to produce an equal change of their insertion loss which over the frequency range of maximum speech energy is the inverse of the change in the receiving loss produced by the adjustment of said volume control attenuator.

22. The telephone set of claim 12 in combination with an interlocking key switch controlled by the local operator, for controlling the energization of said set, connecting it to the selected telephone line, and controlling the received volume level, the sensitivity of the receiving voice-

operated switching circuit and the loss value of the loss networks in the voice transmitting and receiving branches.

23. The combination of claim 17, in which said auxiliary control circuit comprises means responsive to said talker's signal waves at the input of said other switching circuit to apply a direct current bias varying in accordance with the level of said waves to the amplifier in said one switching circuit poled to oppose the varying direct current bias produced thereon by transmission applied to the input of said one switching circuit, and of such magnitude as to prevent operation of said one switching circuit in response to echoes of said talker's signal waves of higher level than the minimum level at which said one switching circuit is supposed to operate.

24. The combination of claim 17, in which said auxiliary control circuit comprises means responsive to said talker's signal waves at the input of said other switching circuit to apply a direct current bias varying in accordance with the level of said waves to the amplifier in said one switching circuit poled to oppose the varying direct current bias produced thereon by transmission applied to the input of said one switching circuit, and of such magnitude as to prevent operation of said one switching circuit in response to echoes of said talker's signal waves of higher level than the minimum level at which said one switching circuit is supposed to operate, the circuit elements in said auxiliary control means having such characteristics with respect to those of the circuit elements in said one switching circuit as to give said auxiliary control means a faster attack time and a smaller holdover time than said one switching circuit.

25. The combination of claim 17, in which each of said switching circuits includes a rectifier followed by an electron discharge amplifying device having a control grid circuit including a hang-over network, and a switching relay controlled by the output current of said device, said device having a normal fixed direct current bias sufficient to prevent operation of said switching relay in response to normal circuit noise applied to said network but permitting operation of said relay from the output of the preceding amplifying device in response to waves of greater level applied to said one switching circuit, and said auxiliary control circuit comprises a half-wave rectifier supplied with waves applied to the input of said other switching circuit, and a second hang-over network in the output thereof and connected in series with the first hang-over network in the control grid circuit of the electron discharge device in said one switching circuit, the values of the circuit elements and the poling of said half-wave rectifier in said auxiliary control circuit being selected so that the direct current biasing voltage varying in accordance with the waves in the input of said other switching circuit, applied by said second hang-over network opposes that applied by said first hang-over network, and is of sufficient magnitude to prevent operation of said switching relay in said one switching circuit in response to the talker's signal echoes reaching the associated voice transmission path.

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